

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Application No.: 10/689,198

Filing Date: October 20, 2003

Applicant: Joseph D. Rainville et al.

Group Art Unit: 1795

Examiner: Alix Elizabeth Echelmeyer

Title: REGENERATIVE COMPRESSOR MOTOR CONTROL FOR
A FUEL CELL POWER SYSTEM

Attorney Docket: 8450G-000213 (General Motors Docket No. GP-303508)

Commissioner for Patents
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Declaration of Joseph D. Rainville Under 37 C.F.R. § 1.132

I, Joseph D. Rainville, declare:

1. I am the first inventor named in this patent application. I have been a practicing Hydrogen Fuel Cell Engineer since October 21st of 1996. I graduated from Rochester Institute of Technology in 1994 with a BS degree in Mechanical Engineering Technology. I continued my education with air compressors and turbomachinery by enrolling in the "Fluid Mechanics of Turbomachines" class at Rochester Institute of Technology in 2002, in addition to a graduate level class in "Centrifugal Compressor Design and Performance" taught by Dr. David Japikse at Concepts NREC (Northern Research and Engineering Corp) of White River Junction, VT. I am

an inventor of four issued patents and fourteen patent applications in the field of Fuel Cells. I am also an author and inventor of 13 publications describing unpatented inventions.

2. I have read and understood Lahiff, U.S. Patent Application Publication No. US 2003/0068538 A1 and Arnold et al., U.S. Patent No. 6,647,724. I understand and am familiar with the technology described in each of these two documents. While there are a few superficial similarities to my invention, the technologies described in the Lahiff and Arnold documents differ significantly in scope and spirit from my invention.

3. The Lahiff application teaches to operate a fuel cell system's electric motor-powered air compressor in a very inefficient manner to dissipate or waste excess electrical power generated by an electric vehicle's regenerative braking system. Electric vehicles typically have the ability to reverse the direction of energy flow in the vehicle's main drive or traction motor. Normally the main drive or traction motor converts electric power into mechanical torque to accelerate the vehicle. During vehicle braking or slowing conditions, the motor can reverse that process to convert mechanical torque to electric power that is typically stored in an on board battery or other electrical storage device. This is done to make the vehicle more energy efficient. Lahiff teaches that when more electrical energy is produced by this method than can be stored on board the vehicle this excess power is sent to the on board fuel cell's air compressor to be converted to mechanical energy as air pressure and flow. This air flow is dumped overboard using a system of valves bypasses the fuel cell stack. Alternately, Lahiff also teaches that if the minimum power request from the vehicle is lower than the minimum power that can be produced by the fuel cell system, the vehicle dissipates the excess power by sending to the air compressor, converting it

into air pressure and flow that it vents overboard. Lahiff does not teach or imply any mechanism to reclaim mechanical energy of the spinning compressor as our invention does. Only our invention reclaims this energy by regeneratively controlling the compressor motor of a fuel cell system to allow the reclaimed mechanical energy converted to electrical energy to be available to the compressor for the next increase in RPM or speed. Lahiff only teaches to run the compressor in an inefficient manner to waste energy, not to conserve it.

4. To quote the first line of the Lahiff abstract: “A method and apparatus for *dissipating energy* in a fuel cell generator system is provided.” (Emphasis added.) The Lahiff application does not state or imply using the compressor-motor unit to create or store electrical energy, only to dissipate excess electrical energy by converting it to air flow and pressure in the air compressor to then vent this flow and pressure overboard.

The Examiner’s statement on page 6 of the office communication dated 2/18/2009 that “So, the compressor of Lahiff et al. is certainly used to generate electricity as well as dissipate it” is not accurate. The Examiner then directs us to see the second sentence of [0011] of the Lahiff application. To quote the first three sentences of paragraph [0011] of Lahiff for context, Lahiff says, “According to one embodiment of the present invention, a method for dissipating electrical power output in a fuel cell power system is disclosed. The fuel cell power system includes a fuel cell stack for generating electric power and a compressor for delivering gas containing oxygen to the fuel cell stack. The method includes the steps of determining an amount of electrical power to be dissipated, operating the compressor to draw electrical current as required to dissipate the power, and valving the compressor to reduce the delivery of gas containing oxygen to the fuel cell stack.” I see no teaching or reference to the compressor being used to create or return

electrical power to the system, only to consume it. In the Lahiff fuel cell system, electric power is generated with either the vehicle regenerative braking system, or the fuel cell stack generates electric power, and that is by the chemical reaction of oxidant and fuel, not by regenerative control of the compressor motor to convert mechanical energy into electricity.

5. Arnold teaches to separate a typical ‘turbocharger’ component into two distinct halves, no longer connected by a common shaft as done on a typical turbocharged internal combustion (IC) application. A turbocharger is used to increase the specific output of an IC engine by raising the manifold air pressure (MAP) and air flow into the IC engine by powering a centrifugal air compressor impeller with an expander wheel on a common shaft converting energy contained in the exhaust gas stream to shaft power. Simply put, “more air + more fuel = more power” as shown in Fig. 7 of the Arnold Patent.

Arnold removes the common shaft between the compressor and expander wheels and replaces them with an electric motor to power the compressor and an electric generator powered by the turbine. Noting line 20 in column 4 of the Arnold Patent, it appears the added mass and complexity of the system is designed to provide instant ‘boost’ to an IC engine, overcoming the common ‘turbo lag’ issue of a typical turbocharger. Turbo lag refers to the time it takes for the turbo to ‘spool up’ and make boost relative to when the driver steps on the accelerator pedal.

To quote the Arnold Patent column 1, first paragraph “Subject matter disclosed herein relates generally to methods, devices, and/or systems for enhancing engine performance through use of an electrically driven compressor and/or turbine generator.” The Arnold patent does not teach or imply to use an electrically driven compressor to convert mechanical energy into electrical energy.

6. The examiner makes several references on pages 6 and 7 of the Office communication dated 2/18/2009 to variable speed compressors and the teachings of Arnold in combination with, and in view of Lahiff. Every variable power or load following fuel cell system would have a variable electrical output, requiring a varying amount of oxidant air, hence variable speed compressor. Arnold's electrically driven variable speed compressor replaces a mechanically driven variable speed compressor. All turbocharged IC engines would have a variable speed compressor, whether powered by an exhaust driven turbine or a shaft or belt drive system from the IC engines crankshaft.

7. Any typical state-of-the-art fuel cell system uses a variable speed electric motor-driven air compressor to provide oxidant air to the fuel cell stack. It is unique to my invention to use that same component to capture the mechanical inertia of reducing its rpm, in response to lowering the power output level of the fuel cell, as electrical power so that this power can be available for the next increase in rpm corresponding to requesting an increase the electrical output of the fuel cell system.

The electric motor driven air compressor that supplies oxidant to a fuel cell stack should generally respond a load change request with an upward transient response time of 10-90% power in approximately 1-second. Therefore, the compressor must respond in similar fashion to supply the required oxidant for the power requested. This rapid response time can cause a short-term power drain several times the compressor motor's rated power. In addition, power is wasted when current is used to brake the motor on a down transient. My invention combats the power drain and assists with transient responses with an energy storage device (such as a

capacitor) and a control circuit added to the compressor motor controller to store braking energy during downward power transients, and release that energy to assist with the upward transients. This control scheme presents several advantages including faster system response and lower power drains on upward power transients. The capacitor can also be charged slowly under normal system operating conditions to keep it fully charged.

I do not find this invention to be obvious in reference to regeneratively braking a vehicle. This invention is used not to reclaim mechanical energy normally wasted by vehicular friction brakes. This invention is reclaiming the rotational energy of a motor driven air compressor to be stored in the compressor motor controlled to be used to increase the response time of the compressor at the next acceleration request. This also reduces the parasitic load of the compressor on the fuel cell stack, allowing the stack power to not be ‘pulled down’ by the compressor power request when the stack is concurrently creating electrical power to propel the electric vehicle it is contained in. Lahiff’s regenerative vehicle braking does not, and cannot, have these features. Nor does Lahiff teach or suggest such features with his fuel cell system compressor.

9. I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true. I understand that willful false statements and the like if made herein would be punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and may jeopardize the validity of the application or any patent issuing there from.

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Date: 16-APR-2009